

T.D. Prowse

Northern Hydrology Section
Hydrology Division
National Hydrology Research Institute
Environment Canada
SASKATOON, Saskatchewan

for

NRCC WORKING GROUP ON RIVER ICE JAMS

GUIDELINES FOR RIVER ICE
DATA COLLECTION PROGRAMS

NHRI Contribution No. 88067⁸⁸⁰⁰⁶

September, 1988

FOREWORD

This report has been prepared for the National Research Council of Canada, Working Group on River Ice Jams and addresses the Group's Task 1: "To develop guidelines for needed data collection programs." The membership of the Working Group is as follows:

- S. Beltaos (Chairman), National Water Research Institute
- D. Andres, Alberta Research Council
- B. Burrell, Environment New Brunswick
- R. Gerard, University of Alberta
- R. Halliday, Water Resources Branch, Environment Canada
- F. Parkinson, La Salle Hydraulic Laboratory Ltd.
- S. Petryk, Tecsalt Ltd.
- T. Prowse, National Hydrology Research Institute

TABLE OF CONTENTS

	<u>Section</u>	<u>Page</u>
	FOREWORD	i
	TABLE OF CONTENTS	ii
1.	INTRODUCTION	1
2.	DATA COLLECTION PROGRAMS	5
2.1.	Other Programs	5
2.2.	Canadian Situation	7
3.	GUIDELINE DESIGN	8
3.1.	General	8
3.2.	Supplementary Observations	9
3.3.	Selection of Study Sites	10
3.4.	Frequency of Observations	11
3.5.	Survey Forms	12
4.	GUIDELINES - ICE OBSERVATION PHASES	13
4.1.	Freeze-up	13
4.2.	Main winter period	15
4.3.	Break-up	18
4.3.1.	Pre-break-up	19
4.3.2.	Break-up	20
4.3.3.	Ice Jams	21
4.3.4.	Post break-up	23
5.	SUMMARY	24
	AKNOWLEDGEMENTS	26
	REFERENCES	27
	FIGURES	
	PHOTOGRAPHS	
	APPENDIX	

1. INTRODUCTION

For a large part of the winter season, ice covers most of Canada's rivers creating numerous and wide-ranging hydrotechnical problems. Detrimental effects caused by the formation, growth and break-up of river ice can be extremely diverse, including for example the forced shut-down of power plants due to frazil accumulation, damage to engineering structures from large ice runs, disruption of normal open water and surface ice transportation, and the flooding of communities by ice jam-induced backwater. Gerard (1979,1984) and Acres Consultants Ltd. (1971) provide reviews of the myriad of problems and present research associated with river ice.

In purely economic terms, the annual Canadian cost due to ice jams alone has been estimated by Atkinson (1973) to be approximately thirty-seven million dollars*. More specifically, Atkinson (1973) calculated that almost four million dollars* is spent annually on just the repair and maintenance of bridges damaged by ice, and that an even greater damage total of over six million dollars* per year is attributable to flooding caused by river ice jams. While these figures do demonstrate some of the high damage costs associated with river ice, it should be remembered that they are only annual averages derived from a seventy year record. Equally high costs can accrue from a single event. For example, Atkinson (1973) cites a major ice jam on the St. John River in 1936 which resulted in damages of approximately thirty-six million dollars* and, more

* Atkinson (1973) calculated damages in 1968 dollars. For comparative purposes, they have been converted in this report to 1988 dollars according to the Statistics Canada, Consumer Price Index.

accrue from a 1:100 year ice jam flood at Fort McMurray, Alberta has been calculated to be over half a billion dollars (Alberta Environment 1982). In addition to the direct costs associated with flood damages, river ice problems can produce more indirect costs to the economy such as through the hindrance posed to navigation. In 1984, for example, a financial loss to the shipping industry of over 1.5 million dollars per day was attributed to an ice jam on the St. Clair River (Nekvasil 1984). Although the above financial costs associated with river ice problems are exceptionally high, it should be noted that they ignore the less tangible, but no less common, damages such as inconvenience, distress, and even loss of life.

Serious and costly ice problems have occurred on most Canadian rivers where an ice cover develops. The broad national scope of the problem is apparent in a compilation of case studies produced by Petryk (1984, 1985) for the National Research Council of Canada (NRCC), Working Group on River Ice Jams. Evidence from an up-dated review of ice jam related damages in Canada, also being prepared for the NRCC Working Group on River Ice Jams, suggests that the incidence of problems and adverse economic effects associated with river ice will increase as development continues to encroach on southern rivers and extends further into the north.

Despite the economic importance of river ice, research activity has been limited, especially in comparison to the extensive work conducted on open channel flow. In fact, for some hydrologic concerns, it would seem more appropriate to focus both data collection and research activities on the

period affected by river ice. In the case of high stage events, for example, historical analyses, such as that conducted by Gerard and Karpuk (1979), indicate that maximum annual stages on many northern rivers result not from high flows during the open water season, as is sometimes assumed, but from high stages produced by river ice jams. Effective flood prediction and damage reduction on such rivers can only be achieved by first obtaining the relevant data about the ice conditions period.

Over the last two decades, significant advances have been made in river ice research, particularly with the development of theoretical models of ice jams (Pariset et al. 1966; Michel 1971; Uzuner and Kennedy 1976; Beltaos 1983a). Unfortunately, further advances and even the testing and calibration of existing models have been thwarted by the dearth of quantitative field information.

Good field data are fundamental to this type of research and a comprehensive, detailed data base is needed if significant new advances are to be made in the understanding of river ice processes.

Because of the relative infancy of river ice research, there exists a host of unsolved problems, each of which requires specific types of field data. In most cases, however, there is a 'bottom line' of fundamental field data which has maximum utility in terms of cost-benefit comparisons. The major objective of this report is to present a set of observational guidelines which have been designed around this 'bottom line' and in consideration of the practicalities and logistical difficulties involved in field data collection programs.

In order that the guidelines be usable by as many groups as possible, the observations have been designed for a user who has limited access to a river and who must perform all monitoring from a single bank location. These design criteria ensure that the guidelines can be used equally well in all parts of Canada, including remote areas where access by road and bridge crossings is rarely found. Such physical limitations frequently apply to local observers who conduct auxiliary observations at hydrometric stations. Observational programs of this type should be relatively easy to expand so as to provide for the collection of river ice data.

It should be stressed that this report is directed towards 'site specific' observations whereby the ice observations and data will be used by future researchers and practitioners to study ice conditions at a given site. These types of observations are simpler than and quite different from 'reconnaissance level' observations where sufficient observations are made along the river to understand the ice regime in a given reach. In the detailed study of ice jams, for example, it is 'reconnaissance level' observations which are usually required. A future objective would be to formulate a second set of guidelines for situations in which monitoring of an entire river reach is possible, preferably by aerial reconnaissance, and where additional personnel could be made available during periods of high activity such as during the formation and release of ice jams. These 'reconnaissance level' guidelines will be designed to supplement the routine or 'site specific' guidelines outlined in this report.

Although the site specific data are not as detailed as the reconnaissance level information, they are still extremely valuable to the solution of a number of research and operational problems. Some of their more immediate utility pertains to the short and long-term forecasting of the initiation of freeze-up and break-up, and the maximum water levels associated with these events. For example, Beltaos (1983b) has had success in developing site-specific forecasting methods, based on a number of years of data of the type described in this report. If similar data is collected from a number of sites, comparative analyses of the site-specific results would most likely lead to techniques for generalization and extrapolation to sites without such historical data. A comparative analysis on a national basis would likely require data from a minimum of 30 sites selected from across the country. The data should be reviewed and appraised at intervals in the order of 5 years.

2. DATA COLLECTION PROGRAMS

2.1 Other Programs

Recognition of the importance of establishing a comprehensive data base for river ice research is not unique to Canada. Other countries and international agencies have identified the same need and, to varying degrees, have attempted to remedy the situation. For example, the World Meteorological Organization (1981,1983) provides instructions for the study of river ice as an integral part of its overall guidelines for hydrological programs, including in particular a) a suggested network

design, instruments and methods of observation, and b) methods of forecasting, both theoretical and empirical. Unfortunately, the types of ice observations suggested by the WMO are rather elementary and fall short of current requirements. One of the major problems in establishing a comprehensive data collection program in some regions or countries is simply the vastness of the area to be monitored. Strong regional variations in ice conditions and physical environments necessitate the study of representative river sites from each different region in order to obtain a truly comprehensive data base. Within the U.S.S.R. attempts have been made to regionally classify river ice break-up processes and patterns based on data from a permanent network of monitoring stations. This work appears to be hampered by two factors. Firstly, although there is a large accumulation of material which describes the cause and condition of the formation of spring ice jams, it is primarily limited to qualitative studies of the phenomenon (Deev and Popov 1981). In recent years, more quantitative analysis has been undertaken in conjunction with attempts to improve the quality and frequency of ice observations at gauging stations (Sofer 1970). Unfortunately, the number of permanent stations observing ice conditions within the U.S.S.R. is still considered insufficient. Survey by aerial reconnaissance has been suggested as the only current operational facility for obtaining data on river ice regimes over such vast territory (Antonov et al. 1973). One of the most elaborate and extensive field data collection programs focusing on river ice problems is conducted in Hungary (Hungarian Water Conservation Bureau 1980, 1981). As part of the national water monitoring program, detailed ice observations are regularly conducted by gauge observers at a number of selected river sites. In addition, specially trained ice observation patrols operate along specific river reaches where ice problems are particularly acute.

The frequency of patrol observation fluctuates with the seasonal ice cycle and the degree of process activity. Observations are normally conducted on a daily basis during freeze-up, temporarily suspended during the mid-winter, and then re-introduced on a continuous basis during spring break-up and periods of ice jamming. The entire monitoring program is supplemented by photogrammetric stations located at selected gauge sites, specially trained observers stationed on ice breakers, and a system for processing, classifying, and storing the observational data.

2.2 Canadian Situation

Within Canada there are a number of private and public agencies involved with the collection of river ice field data. On a national scale, two agencies of Environment Canada, Water Survey of Canada and the Atmospheric Environment Service, collect ice data from numerous stations across the country. Canada has geographic problems, in terms of scale and regional differences in river ice conditions, which are similar to those encountered in the U.S.S.R. Moreover, much of the data which have been collected by the national agencies suffer from the same shortcomings. Elementary information, such as ice thickness and dates of freeze-up and break-up, is systematically collected but has only limited utility for river ice studies. More detailed quantitative field data have been collected by private consulting firms, hydro-electric companies and other government agencies, such as the National Hydrology Research Institute, the National Water Research Institute, the Alberta Research Council, and provincial conservation authorities. In many cases, however, these agencies have conducted site specific studies focused on a single research interest.

As a result, disparate data are often collected which are difficult to compare and sometimes to access. In response to this problem, Petryk (1984,1985) has compiled a casebook on ice jams which should improve the accessibility to at least this type of river ice information.

Despite all the data collected in the various case studies and by the national agencies, there still remains a definite scarcity of river ice information about many Canadian rivers and about some important river ice processes. Since it is unlikely in the immediate future that a single agency will be given the mandate to collect the necessary data, the next best step for improving the current data base is to define a set of guidelines for data collection which a) can be readily used by any individual or agency interested in river ice processes and b) most effectively addresses the needs of current river ice research.

3. GUIDELINE DESIGN

3.1 General

The set of river ice observations suggested in this report (Section 4) are ordered in a typical chronology over the winter months, although it should be recognized that a river ice regime is a function of climatic and hydro-geomorphic conditions. For example, the process of ice jamming is not exclusively limited to spring break-up, but may also occur during freeze-up and the main winter period, particularly in the warmer, more temperate regions of the country. Frequently, mid-winter melt events can induce break-up and ice jamming which is soon followed by a return to

colder winter temperatures and a resumption of the freeze-up processes. For such irregular conditions, use of the guidelines should be adjusted accordingly.

Each temporal phase of the guidelines is introduced by a brief description of the objectives in collecting the data and some indication of their ultimate utility. Figures 1 to 4 illustrate the types of observations to be conducted at each phase. Uses of these data are quite wide-ranging, and a complete description of their potential benefits is beyond the intended scope of this report. An overall appreciation of their utility can be obtained, however, in the previously mentioned reviews of research priorities. To obtain an introduction to the broad range of river ice literature, readers are referred to Ashton (1980,1986), Department of the Army (1982) and Michel (1971).

3.2. Supplementary Observations

Although the guidelines have been principally designed for use by individual observers who are restricted to making visual observations from a single shore location, it was also recognized that some observers may have access to additional equipment or personnel which would permit the recording of other site specific information. In particular, two types of supplementary observations - ice thickness and river discharge - would be extremely valuable to the understanding of the river ice regime. In the case of ice thickness and stratigraphy, holes would have to be drilled in the ice sheet to permit the measurement of individual snow and ice strata. For most regions, this additional observation could be carried out by a single observer with relatively simple drilling

equipment. In contrast, discharge is a much more complicated measurement and requires additional personnel and specialized equipment. Individual observers would not be capable of undertaking field measurements of discharge. Where the personnel and equipment are available, however, it is strongly recommended that efforts be made to obtain direct measurements of discharge.

In view of the importance of these two types of supplementary observations and the number of existing observational programs which could record this type of information, appropriate data collection guidelines have been included in section 4. For individual observers who lack the necessary additional equipment or personnel, these supplementary observations will have to be forgone and the remainder of the shore-based observations conducted as outlined.

3.3. Selection of Study Sites

A high proportion of the users of these guidelines are expected to be agencies or organizations which already operate some form of hydro-data collection program. In such cases, the river ice observations will probably be incorporated as part of an existing data collection program, and the location of observation sites will therefore be pre-determined. Notably, however, the combining of programs may affect the type of ice observation data which are collected. For example, the Water Survey of Canada normally selects straight river sections, devoid of any major obstacles to flow such as islands or shoals, at which to establish gauging sites. The probability of collecting observations of ice jams at such sites may therefore be low. In cases where new study sites are

being selected, or existing data collection programs are being expanded, a number of selection criteria should be considered which will assist both in the monitoring of river ice conditions and in future research analyses. Firstly, a river gauging site and meteorological station, both with reliable records, should be in close proximity. Sites with more than one good vantage point from which to conduct upstream and downstream observations are preferred. Access to a bridge is ideal and creates the added opportunity of obtaining discharge measurements immediately following, and possibly during, break-up.

If a number of sites are to be selected and studied by one agency, care should be taken to obtain a varied sample of representative reaches from the whole study region. In terms of a national program, representativeness should be addressed under such categories as river size, geomorphology and climate.

3.4. Frequency of Observations

In situations where ice observations are incorporated as part of an existing data collection program, the timing of observations may be largely controlled by the established frequency of site visitation. It should be remembered, however, that one of the major reasons for the scarcity of good field data from some water data collection programs is the relatively low frequency and untimeliness of site visits in comparison to the degree of river ice activity. Perhaps the scheduling of some existing field programs could be modified to allow for more frequent site visits during the river ice period, particularly during freeze-up and break-up.

If incorporating additional visits and observations within existing programs is not logistically feasible then perhaps additional field personnel could be made available whose primary objective is to conduct observations during the river ice period.

The frequency of site visits should ideally correspond with the degree of river ice activity. During freeze-up, daily visits should be made. Once an intact ice cover has been established, visits can be reduced to one every two or four weeks, the frequency increasing as the break-up season approaches. After appreciable melt has occurred, observations should again be conducted on a daily basis with as many observations per day as possible during the main break-up period. Further details regarding the frequency of specific observations are included in section 4.

3.5. Survey Forms

Appendix A contains two examples of forms which have been developed to assist in the collection of river ice observations. The first form, 'ICE SURVEY NOTES', is a modified version of an earlier form (Anderson and Prowse 1983; Prowse and Anderson 1984) which was designed to be compatible with the standard field measurement forms used by the Water Survey of Canada. The rows and columns on page one are for entering thickness data from a cross-section profile of a stable ice cover. These data can normally be collected when holes are drilled through the ice for the measurement of discharge. As earlier noted, such measurements can only be conducted in cases where the personnel and appropriate equipment are available. The remainder of the form can be completed by an individual making observations from a bank location. Spaces and appropriate headings are included to assist in recording most of the

observations outlined in this report. Separate parts of the form are devoted to the recording of freeze-up, break-up, and ice jam observations. The second form (Beltaos 1984) can also be used by a shore observer and is broken primarily into sections on open water, moving ice and stationary ice.

One important feature of both forms is the inclusion of space for sketches of river ice processes and a note indicating that photographs should be taken whenever possible. Any form of imagery, whether hand-sketches or photographs, is invaluable to the final interpretation and analysis of the data, especially where this work is conducted by someone other than the ice observer.

4. GUIDELINES - ICE OBSERVATION PHASES

4.1. Freeze-up

During freeze-up, accumulation of ice within a river changes the open water relationship between stage and discharge. The degree of distortion is primarily dependent on the form, thickness and roughness of the accumulating ice cover. Knowledge of the freeze-up processes is critical to the interpretation of stage records, the assessment of discharge, and ultimately to predictive modelling of freeze-up. Freeze-up characteristics have also been shown by Shulyakovskii (1966) and more recently Beltaos (1983b) to have important ramifications for break-up. In particular, the stage required to initiate break-up and the maximum stage reached during break-up has been found to be closely linked to the

stage at freeze-up. Even the structure of the freeze-up ice cover can be important to the decay and fracturing of the ice cover at break-up.

The main types of observations to be taken during freeze-up include: stage, discharge, ice types, concentration, method of freeze-up, nature of the ice cover formed, and rate of upstream progression (Fig. 1).

a) Stage and discharge: Monitor the stage leading to freeze-up, particularly at the time of formation of the first permanent ice cover. Under some conditions, the annual peak stage occurs during freeze-up. Measure or estimate discharge before and after freeze-up.

b) Ice types and concentration (Photograph 1)

Border ice: Border ice is composed of ice which has gradually grown outwards from the shore or from exposed objects in the channel, and/or from drifting ice (primarily frazil ice) which has accumulated along the ice-water margin. Where border ice is subject to water level fluctuations, repeated flooding and freezing of river water can produce a layering of abnormally thick ice along the banks. Note the type, thickness and lateral extent of border ice.

Floating ice: Estimate the dimensions, distribution, and concentration of frazil (or other) ice passing through the river reach. Where close inspection of the ice can be made, provide a qualitative estimate of ice strength and porosity. In the case of frazil pans, note the thickness of the overall pan and the surface crust.

c) Method of freeze-up: Describe whether the formation of the final complete ice cover results from the lodgement or bridging of ice particles across the section or from the accumulation of ice particles against a downstream ice cover (Photographs 2,3 and 4). Note the rate of upstream progression of the freeze-up front through the observable river reach.

d) Nature of freeze-up ice cover: Describe the surface of the final ice cover with particular reference to surface roughness and ice types. Estimate overall thickness.

4.2. Main winter period

Ice growth during the winter season determines the quantity and strength of ice which must be removed at break-up. Since break-up does not necessarily occur at the same time each year, and ice thickness may vary depending on the severity of winter conditions, regular monitoring of ice thickness is necessary. Because of spatial variations in ice thickness, a number of measurements taken across the river cross-section is preferred. In cases where such measurements are taken as part of a winter discharge measurement, the total ice thickness (ie. top to bottom of ice cover) should be measured rather than the common measurement of the thickness of ice beneath the water surface which is used in deriving the depth of flow beneath an ice cover.

Attempts should also be made to record the general stratigraphic composition of the ice cover when thickness is measured. In the simplest case, (Photograph 5) the top of the ice cover will be comprised of an upper strata (often multiple layers) of relatively opaque, white ice formed from frazil accumulations at freeze-up and the slushing and refreezing of surface snow. Beneath this ice will be a more transparent 'blue' or 'black' ice formed by the downward freezing of river water. The interface between these two strata can best be observed by drilling a hole part way into the ice cover, so as not to allow water to fill the hole, and then inspecting the side of the drill hole. In addition to differences in visual appearance, these two layers are distinguishable by differences in texture along the side of the drill hole. The surface layers of white ice will be characterized by a rough granular texture while the underlying layer of black ice will generally be much smoother. Once the location of the interface between these two layers is determined, drilling of the hole can be completed and total ice thickness measured. The presence of frazil ice accumulations beneath the main ice cover should also be noted (Photograph 6). The thickness of frazil ice beneath the ice cover can usually only be determined from vertical profiles of water velocity beneath the ice cover.

It should be stressed that the above describes only the simplest case of river ice stratigraphy. The composition of river ice is often so complex that observers will be able only to accurately measure total snow and ice thickness. Where an ice cover has evolved from a complex assortment of freeze-up and growth processes, identification of major strata can only be accomplished by extracting an ice block or ice core, a procedure which requires resources beyond those described for this set of guidelines.

Further discussions of river ice types can be found in, for example, Ashton (1979, 1986) and Michel (1971).

The major types of observation to be taken during the main winter period include: stage, discharge, snow and ice thickness, ice cover composition, and surface ice appearance and shape (Fig. 2).

a) Stage and discharge: Monitor the stage during the winter period paying particular attention to periods when the ice cover drops, because of recession in flow and erosion of frazil deposits, and forms hinge cracks (Photograph 7). Discharge measurements should be made frequently enough to produce a reliable discharge recession curve.

b) Snow and ice thickness: Measure the thickness of the surface snow cover and thickness of the underlying ice cover at a number of points across the river cross-section.

c) Cover composition: When measuring ice thickness, note the thickness of different ice layers and the presence of frazil accumulations beneath the main ice cover.

d) Surface ice appearance: Note the surface roughness of the ice cover, including the location of pressure ridges and other areas where the ice appears to be grounded, and the presence of shear lines along the shore.

4.3. Break-up

Systematic documentation of break-up conditions over a number of years will lead to a refinement of existing classifications of break-up processes and to a better understanding of the physical mechanisms which control break-up. One of the more immediate benefits of the data will be the opportunity to develop site-specific forecasting capability of ice conditions. Over the longer term, the probability of specific break-up events will hopefully be linked to measureable morphologic and hydrometeorologic characteristics which can then be used to extrapolate forecasting capabilities to other areas.

Of all the break-up observations, special efforts should be made to obtain accurate records of maximum stage. For most rivers, break-up is typically the period with the poorest stage record because of the damage to stream-implemented recording devices by moving ice. Manual surveys of stage should be conducted during each visit and notes made of any recent high water marks or strand lines. Where resources permitted, crest-stage gauges and time-lapse cameras have been used in attempts to improve the stage record during break-up.

Because ice jams are responsible for the highest water levels on many rivers, information should be collected regarding their mode of initiation and failure, their effect on stage, and even their size in terms of elementary parameters such as length, depth, and width. This type of information will provide direction to further field, laboratory and theoretical studies.

Because of the complexity of the break-up process, observations have been broken into four periods: pre-break-up, break-up, ice jams and post break-up. The possibility of obtaining many of the listed observations depends on the position of the observer relative to specific break-up forms and processes, particularly ice jamming.

4.3.1. Pre-break-up (Fig. 2)

a) Stage and discharge: Stage should be measured daily until the water level approaches the freeze-up level. The frequency should then be increased (every eight to twelve hours) especially if mild weather has set in and significant attendant runoff is anticipated. Special efforts should be made to obtain a flow measurement as close to the time of break-up as possible.

b) Snow and ice thickness: Once the main snowmelt period has begun, a final survey of snow and ice thickness across the reach should be made before the surface becomes unsafe for travel.

c) Cover composition: In conjunction with the final thickness survey, note the thickness of the different ice layers including surficial ice forms and frazil accumulations beneath the main ice cover. As water begins to saturate the snow and ice, individual strata will become increasingly difficult to distinguish.

d) Surface conditions: Once surface travel is unsafe, note the percentage cover of snow and exposed ice, the presence of ponded meltwater, and when the water drains from the surface. The ice surface often has a dark appearance when covered with meltwater but quickly brightens after draining.

e) Shore conditions: Note the depth and width of any water accumulating near the shore and if any flow is apparent. Also describe the formation, size and position of any major cracks, and note when the main ice cover 'lifts' and detaches from the shore. Lifting of the ice sheet is usually concomitant with the draining of surface meltwater. Note whether bottom fast ice is present beneath the shore lead.

4.3.2. Break-up (Fig. 3)

a) Stage: Water levels should be monitored as frequently as possible. Points of specific interest include: the rate of rise in water level immediately prior to the initial fracturing and movement of the ice sheet, water levels at the time of first ice movement, the maximum break-up water level, and changes in water level as fractured ice clears the study reach.

b) Break-up front: The character of a break-up front can vary considerably but there are usually two distinct styles. The first involves a rapid transition from intact ice cover to highly fractured ice (Photograph 8). In such cases estimate the rate at which this fractured break-up front moves downstream. The second style is characterized by a large scale fracturing of the ice sheet followed by a downstream movement

of large pans which often rotate and fracture within the flow (Photograph 9). In this second case, estimate the speed at which the initial pans move downstream. In extreme cases (thermal break-ups) the ice cover will almost melt in situ (Photograph 10).

4.3.3. Ice jams (Figs. 4,5)

In cases where the clearance of fractured ice from the study reach suddenly stops, formation of a jam downstream can be assumed. The type of observations to be taken then depend on the position of the observer relative to the various parts of the jam. If the observer has good vantage of other parts of the river, or access to other sites, every effort should be made to observe as much of the ice jam as possible. Even where observations are limited to one site, if final clearance of the jam can be monitored, the observer may be able to estimate what other characteristics of the jam may have been, such as location of the head (upstream end of ice jam, see Fig. 5) and jam length.

a) Stage and discharge: Water levels should be monitored as frequently as possible. Points of specific interest include: the rise in water level when the moving ice stops, the maximum water level while the jam is in place, and the water level when the jam breaks and ice again begins to clear from the reach.

If other points are accessible along the ice jam, make notes of the water level at each site relative to local objects which can be later surveyed to obtain real elevations.

Estimate the velocity of the break-up front which lead to formation of the ice jam and the velocity of surface ice when the ice jam releases.

b) Areal extent of ice jam: Note whether the ice completely or only partially blocks the river cross-section. If visible, also record the location of the downstream (toe) and upstream (head) portions of the jam (Figs. 4,5)

c) Conditions at toe of ice jam: If the ice jam toe is visible, describe whether the jam has been either i) forcibly halted by some downstream obstruction, such as an intact ice cover (see Fig. 5), man-made structure, geomorphic feature (shoal, sharp bend), etc. or ii) stopped by the lodging or bridging of ice floes across the river channel (similar to freeze-up situation in Photograph 2). If possible make a discharge measurement downstream of the toe where no backwater effects are apparent.

d) Conditions at head of ice jam: If the head of the ice jam is visible, estimate the size (dimensions of floes) and concentration (percentage of river surface covered) of incoming ice. Also note whether the ice is adding to an upstream extension of the jam or is being entrained underneath the jam. If possible make a discharge measurement upstream of the ice jam (see notes under post break-up).

e) Surface conditions: Note the roughness and texture of the ice jam surface. Estimate the distance from shore of any shear lines which have formed from differential movement within the ice jam. Attempt to identify whether the jam is comprised of a single layer of floes or if

there has been noticeable compaction and thickening of the jam. Note also if the surface is 'buckled' or has localized ice mounds. This may indicate that ice is grounded on the river bed. Record the presence of any major ice shoves (Photograph 11).

4.3.4. Post break-up (Fig. 4)

a) Stage and discharge: Continue regular monitoring of water levels until the majority of floating ice has completely cleared from the study reach. Discharge measurements during the active break-up period are normally not available for hydrometric sites in Canada, largely because of the lack of safe access and the relatively short duration of the break-up period. Where access is available, such as from a bridge spanning the river reach, discharge should be measured as soon as the river becomes sufficiently clear of floating ice to allow the lowering of current meters. Details should be provided regarding the stability of the flow at the time of the measurement and the relative location of any ice accumulations in the river both upstream and downstream of the measurement site. Observations of stage and discharge should continue until backwater effects due to ice disappear.

b) Ice thickness: Measure the thickness of ice floes which have been stranded along the shore. Where possible use ice floes which show a complete stratigraphy and disregard those which have been sheared in cross-section or badly deformed by ice jam forces. Provide a brief description of the quality or structural integrity of the ice floes, such as whether the ice is heavily candled or remains relatively competent.

c) Shear wall dimensions: Following the clearance of an ice jam, there often remain large masses of strongly deformed ice which have been 'plastered' along the shore. The outer edge of these masses is normally marked by a very precipitous edge termed the shear wall (Photograph 12). Once the water level has receded, to the point where the base of the shear walls becomes exposed, measure or estimate the overall height of the wall and its distance from the channel bank. This gives a good indication of ice jam thickness, a parameter of crucial importance in ice jam research.

5. SUMMARY

This set of data collection guidelines was developed in response to an expressed need for a coherent and extensive data base concerning river ice processes. The existing data base is unsatisfactory because of the brevity of most site records, the lack of uniformity in the types of collected data, and the scarcity of detailed information for many parts of the country. The structured format of these data collection guidelines will hopefully lead to the assembly of a uniform data base beneficial for operational as well as research purposes.

The observations have been selected based on the needs of current and future river ice research, while also considering the difficulties and practicalities of field monitoring programmes. In general, the observations can be made by a single individual who has only limited access to a river. This criterion ensures wide-spread usability of the guidelines.

The next step in developing a comprehensive data base will be the design of a further set of 'reconnaissance level' guidelines which can be used by agencies and researchers for more intensive studies of a smaller number of sites. At this level, entire river reaches will be monitored and much more elaborate observations will be possible with additional personnel and equipment. The more sophisticated set of observations will serve to augment, rather than replace, those outlined in this report.

ACKNOWLEDGEMENTS

Contributions and reviews by members of the NRCC Working Group on River Ice Jams (p.i), M. Alford and L. Kamp of the Water Resources Branch, J.C. Anderson, D.K. MacKay and C.R. Onclin of the National Hydrology Research Institute, and Dr. W.P. Adams of Trent University are gratefully acknowledged. Special thanks to S.C. Gardiner of Trent University for the illustrations.

REFERENCES

- Acres Consultants Ltd. 1971. Review of current ice technology and evaluation of research priorities. Inland Waters Branch, Department of Environment, Report No. 17, Ottawa, 299 pp.
- Alberta Environment 1982. Fort McMurray, Flood Damage Reduction Program, Phase II-B, Flood Damage Estimates. Technical report prepared by ECOS Engineering Services Ltd.
- Anderson, J.C. and T.D. Prowse. 1983. A field survey form for monitoring ice conditions on lakes and rivers. Proc. 40th Eastern Snow Conference, Toronto, Ontario, June 1983, 198-200.
- Antonov, V.S., V.V. Ivanov and Yu. V. Nalimov. 1973. Types of breakup of rivers in Siberian arctic and sub-arctic zones. Proc. Banff Symposium, The Role of Snow and Ice in Hydrology, September 1972, IASH No. 107, 541-546.
- Ashton, G.D. 1979. River ice. Am. Sci. 67(1): 38-45.
- Ashton, G.D. 1980. Freshwater ice growth, motion, and decay. Chapter 5. In: Dynamics of Snow and Ice Masses, S.C. Colbeck (ed.), Academic Press, New York, 468 pp.
- Ashton, G.D. (Ed). 1986. River and lake ice engineering. Water Resources Publications, Littleton, Colorado, 485 pp.
- Atkinson, C.H. 1973. Problems and economic importance of ice jams in Canada. Seminar on ice jams in Canada, Edmonton, Alberta, May 1973, NRC Tech. Memo. No. 107, 1-16.
- Beltaos, S. 1983a. River ice jams: theory, case studies and applications. J. Hydraul. Div. ASCE 109, 1338-1359.
- _____. 1983b. Guidelines for extraction of ice-breakup data from hydrometric station records. Draft report. Working Group on River Ice Jams, Subcommittee on Hydraulics of Ice Covered Rivers, Associate Committee on Hydrology, National Research Council of Canada.
- _____. 1984. Unpublished form. National Water Research Institute, Environment Canada.
- Department of the Army. 1982. Ice engineering. U.S. Army Corps of Engineers, Washington, D.C. Engineer Manual No. 1110-2-1612.
- Deev, Iu.A. and A.F. Popov. 1981. Spring ice jams in stream channels. TL 759. U.S. Army Cold Reg. Res. Eng. Lab., Hanover, New Hampshire. 180 pp.
- Gerard, R. 1979. River ice in hydrotechnical engineering, a review of selected topics. Proc. Canadian Hydrology Symposium:79, May 1979, Vancouver, British Columbia. NRCC No. 17834, 1-29.

- _____. 1984. Ice jam research needs. 3rd Workshop on the Hydraulics of River Ice, June 1984, Fredericton, New Brunswick, 181-193.
- Gerard, R., and E.W. Karpuk. 1979. Probability analysis of historical flood data. J. Hydraul. Div. ASCE, 105, 1153-1165.
- Hungarian Water Conservation Bureau. 1980. Hydrological measurements, ice phenomena; Technical handbook of hydrology. Translated from Hungarian by the Translation Bureau, Department of the Secretary of State, Ottawa, 1983.
- _____. 1981. Primary data processing of hydrological measurements, data on ice phenomena; Technical handbook of hydrology. Translated from Hungarian by the Translation Bureau, Department of the Secretary of State, Ottawa, 1983.
- Michel, B. 1971. Winter regime of rivers and lakes. Monogr. III Bla. U.S. Army Cold Reg. Res. Eng. Lab., Hanover, New Hampshire.
- Nekvasil, G. 1984. Spokesman for the Lake Carriers Association. Quotation in Toronto Globe and Mail, April 25, 1984, p. 11.
- Pariset, E., R. Hausser and A. Gagnon. 1966. Formation of ice covers and ice jams in rivers. J. Hydraul. Div. ASCE 92, 1-24.
- Petryk, S. 1984. Case studies concerned with ice jamming: a compilation of descriptions from contributors. 3rd Workshop on the Hydraulics of River Ice, June 1984, Fredericton, New Brunswick, 113-126.
- _____. 1985. Casebook on ice jams. Draft report. Working Group on River Ice Jams, Subcommittee on Hydraulics of Ice Covered Rivers, Associate Committee on Hydrology, National Research Council of Canada.
- Prowse, T.D. and J.C. Anderson. 1984. A field survey form for monitoring ice conditions on lakes and rivers. 3rd Workshop on the Hydraulics of River Ice, June 1984, Fredericton, New Brunswick, 425-430.
- Shulyakovskii, L.G. (ed.) 1966. Manual of forecasting ice-formation for rivers and inland lakes. Leningrad 1963. (Translated from Russian in 1966 by Israel Program for Scientific Translations).
- Sofer, M.G. 1970. Some hydrologic characteristics of ice jam formation on the Lovat River. Sov. Hydrol. Sel. Pap. 2, 193-198.
- Uzuner, M.S. and J.F. Kennedy. 1976. Theoretical model of river ice jams. J. Hydraul. Div. ASCE 102, 1365-1383.
- World Meteorological Organization. 1981. Guide to hydrological practices, Volume 1: Data acquisition and processing. WMO - No. 168.
- World Meteorological Organization. 1983. Guide to hydrological practices, Volume 2: Analysis, forecasting and other applications. WMO - No. 168.

APPENDIX A

RIVER ICE MONITORING FORM

Site _____ Observer _____ Date _____ Time _____

Staff Gauge (if applicable) _____ m at _____ h

ICE CONDITIONS

Open Water: Yes/No. Where _____

Moving Ice: Yes/No. Where _____

What Kind: (1) Slush/Pancakes/Large Sheets/Floes/Small Blocks/Other _____

Stationary Ice: Yes/No. Where _____

What Kind: Pancake Ice/Sheet Ice/Blocks (Jam)/Other _____

Ice Thickness: (2) _____ cm Ice Quality: (3) _____

Snow Cover: Yes/No. Approximate Depth _____ cm

Photo (Looking Upstream/Downstream/Left Bank/
Right Bank) or Sketch. Time _____ h

Other Notes: (4)

- (1) Underline one or more items.
- (2) Give values as measured across the channel, if applicable.
- (3) Use such words as competent, deteriorated, candled.
- (4) Record such additional information as water on top of ice; unusually fast or slow current; presence of ice jam and locations of upstream and downstream ends if visible; overbank flow; presence and configuration of shear walls; etc.